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Enhancing The Strength Of Recycled Aggregate Concrete Incorporating Nanosilica Synthesized From Rice Husk Ash

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Abstract. Environmental and sustainability issues have transpired as a result of the fast population increase, ascending construction and demolition activities, so there is a need for new materials and construction waste management. This study investigates the use of nanosilica extracted from rice husk ash and recycled aggregates (RA) extracted from demolition sites. RA mechanical qualities were assessed, and nanosilica made from rice husk ash was added to concrete with different nanosilica dosages (0.4%, 0.8%, and 1.2%) along with 50% and 100% recycled aggregate substitutions. Tests of compressive strength revealed that nanosilica greatly increased the strength, validating RA as a workable and sustainable substitute material. Rice husk can also be a precursor for nanosilica production, promoting reuse and sustainability in construction.

KEYWORDS: Compressive strength, Nanosilica, Recycled Aggregate, Rice husk, sustainable.

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1. INTRODUCTION

Increasing Population, rapid urbanization and infrastructure development have left a footprint for a significant increase in construction and demolition waste worldwide. The waste produced from demolition and infrastructure development contains a significant amount of concrete, in which 60–70% of its volume is the aggregate, so there exists a need to reduce the amount of Recycled aggregate sustainably. Recycled aggregates are those aggregates obtained from the reconstruction and demolition sites, which can be retreated and used for construction again, and can replace conventional or natural aggregate fully or partially.

Reduce, Reuse and Recycle can be fully promoted by using recycled aggregate concrete in concrete waste management [1]. Replacing 25% of natural aggregate with recycled aggregate in concrete has given a significant compressive strength, which promotes its use [2]. Also, when the percentage increases from 30%, there has been a significant reduction in the compressive strength of concrete, which suggests using beyond 30% is not applicable [3]. The incorporation of nanosilica with recycled aggregate concrete beyond 30% has demonstrated improvements in compressive strength as well as the microstructure of concrete [4].

Nanosilica is ultrafine particles of silicon dioxide (SiO_2) with sizes typically ranging from 1 to 100 nanometers. Because of their nanoscale dimensions, they possess a remarkably high surface area, enhanced reactivity, and unique physicochemical properties compared to conventional silica. Nanosilica can be extracted from rice husk ash in a significant amount [5]. There has been a question why Rice husk, rice husk despite being a waste which is often discarded or burnt that contributes on environmental pollution it is the abundant agricultural byproduct which contains 15–25% of amorphous nanosilica within so rice husk can be a precursor for nanosilica [6] as there will not be a problem of source for it with Nepal being an agricultural country and it is our prime thing to do. Extracting nanosilica from rice husk not only promotes waste management but also provides a new cost-effective and eco-friendly alternative to conventional chemical synthesis methods.

An attempt is made in this paper to combine nanosilica obtained from agricultural waste, rice husk ash, and recycled aggregate obtained from demolition waste, as the effect of naturally derived nanosilica on site-extracted RAC's over 30% is largely unexplored which can be the best alternative to replace natural aggregate in significant amounts for desirable compressive strength enhanced by nanosilica which ultimately promotes sustainability in concrete waste management while creating new opportunities for advanced material applications.

2. LITERATURE REVIEW

Recycled Aggregate can be extracted from demolition sites and reconstruction sites, which can further be used to replace natural aggregate. Also, nanosilica can be extracted from rice husk ash. Many researchers have explored the potential of nanosilica and recycled aggregate as a source of promoting sustainability and solid waste management [7, 8] successfully synthesised nanosilica from rice husk ash using the sol-gel chemical extraction method. It involves the burning of rice husk to get rice husk ash, followed by alkali extraction and acid precipitation. The extraction was also justified with the XRD and FTIR results. [9] Studied the alkali extraction of silica from rice husk and its conversion into silica gel by dissolving rice husk ash in sodium hydroxide, which was further followed by acidification. [3, 10] Studied the feasibility of RAC and concluded that up to 30% replacement of NA with RA can achieve desired results, but beyond this level, strength reduction is distinct. [2, 11] Studied the recycled aggregate to replace natural aggregate with the required compressive strength, which results in a 25% replacement that can be a viable option. [4] examined the effect of using nanosilica (0.4%, 0.8% and 1.2%) with recycled aggregate (50% and 100%) in concrete which resulted in enhancing the compressive and tensile strength and reducing water absorption, indicating enhanced microstructural performance. [12] Studied the combined effect of nanosilica and natural fibres in RAC, which resulted in a 22.5% increase in compressive strength and a 25.6% improvement in flexural strength with 0.3% nanosilica.

While several research proves the potential use of rice husk, nanoslica and recycled aggregate, the effect of naturally derived nanosilica on site-extracted RAC's over 30% is largely unexplored.

3. RESEARCH METHODOLOGY

3.1. **Study Area.** Chitwan district was the primary location for the study. Various demolition sites inside Chitwan district were observed. Naurange, Gholbazar and Bhojad areas were chosen because there was a possibility of a high ratio of extraction of recycled aggregate. Also, the rice husk was taken from the Geetanagar area for nanosilica extraction.

3.2. **Methodology.** Rice husk was collected from local rice mills of Geetanagar and was thoroughly washed to remove dirt and impurities. Afterwards, the grinding was done, and then it was passed through a sieve of 300 μm to obtain uniform particles. Then the sample was placed in a muffle furnace and heated at 350 °C for 3 hours. After heating it was allowed to cool finally rice husk ash was obtained. Then rice husk ash was dissolved in 1M sodium Hydroxide solution to get sodium silicate solution, which was placed in a magnetic stirrer for 2 hours to mix it thoroughly, then placed it in water bath and hydrothermal for constant heating at about 90 °C for 2 hours. Afterwards, the sample was left to cool and filtered, and a clear solution was obtained, which was taken, and 1M of Hydrochloric acid was added dropwise until the pH reached 7 and silica gel started to precipitate. Then silica gel was left to age for 6–12 hours. Finally, the gel was filtered and washed, after which it was placed in the muffle furnace for about 2 hours at 110 °C to get silica powder. The obtained nanosilica was characterized by using FTIR to support its validity.
Concurrently, Recycled aggregate was collected from the demolition sites of Chitwan. As it contained residues of the previous structure and was of an appropriate size, it was manually hammered, and sieve analysis was done to remove the residue and to get the desired size of aggregate. Afterwards, it was washed and sun-dried. Then the various tests on aggregate was done to find whether aggregate is suitable for construction or not. The tests include water absorption, Los Angeles abrasion, and impact test following IS 2386 [13].
Then the proportion of the components to prepare M20 concrete using a nominal ratio of 1:1.5:3 and a water-cement ratio of 0.5 was started, which includes 0%, 50% and 100% recycled aggregate replacing Natural aggregate, along with 0.4%, 0.8% and 1.2% nanosilica by weight of cement was added as an admixture. The number of cubes per proportion was 6, so that it would be tested in 3 cubes each in 14 and 28 days, which totals the cubes to be 42 numbers at the total of all proportions. The standard concrete cube specimen used for compressive strength testing has dimensions of 15 cm × 15 cm × 15 cm, giving a total volume of:

$$V = 0.15 \times 0.15 \times 0.15 = 0.003375 \text{ m}^3 \tag{1}$$

Based on the mix ratio 1:1.5:3 (Cement : Fine Aggregate : Coarse Aggregate), the material quantities required for casting one cube specimen are calculated proportionally from 1 m^3 of concrete.

Material Quantities for One Cube:

- Cement: 1.36 kg
- Fine Aggregate (Sand): 2.19 kg
- Coarse Aggregate: 4.22 kg
- Water (w/c $\approx$ 0.5): 0.68 L

Nano Silica (NS) Content: Nano silica is used as an admixture and is calculated as a percentage of cement content:

- 0.4% NS = 5.44 g
- 0.8% NS = 10.88 g
- 1.2% NS = 16.32 g

Recycled Aggregate (RA) Replacement: For coarse aggregate replacement:

- **50% RA mix:** Natural Aggregate (NA) = 2.11 kg, Recycled Aggregate (RA) = 2.11 kg
- **100% RA mix:** Natural Aggregate (NA) = 0 kg, Recycled Aggregate (RA) = 4.22 kg

Thus, for casting one standard concrete cube, approximately 1.36 kg of cement, 2.19 kg of fine aggregate, 4.22 kg of coarse aggregate, and 0.68 L of water are required, along with the specified dosage of nano silica depending on the mix proportion.
With finalizing the weight of every component, the dry mix was done and an adequate amount of water wet mix was done. Then the Slump test was carried out in order to know whether the concrete is workable or not. After knowing that it was workable, the concrete mix was placed inside the cube moulds with proper compaction. After 24 hours, the cube was separated from the mould and kept for curing in the water tank for 28 days.
Then, finally, the compressive strength test was done on 14 and 28 days on all the proportions. Afterwards, a relation comparison was done to find out whether RA can be an alternate option for NA or not.

4. RESULTS AND DISCUSSION

With the two methods used for the extraction of nanosilica, which were using a water bath (18.56%) and hydrothermal, it suggests that water bath can be a good method to extract a higher volume of nanosilica, which can be a viable option to use on concrete preparation. But the higher yield was from hydrothermal, which was about 20.8%. Figure 1 also confirms the successful formation of amorphous nanoslica as the strong and dominant peak at 1046 cm^{-1} represents the asymmetric stretching vibration of (Si–O–Si) [9], which is the characteristic band of silica and confirms the formation of a silica network.

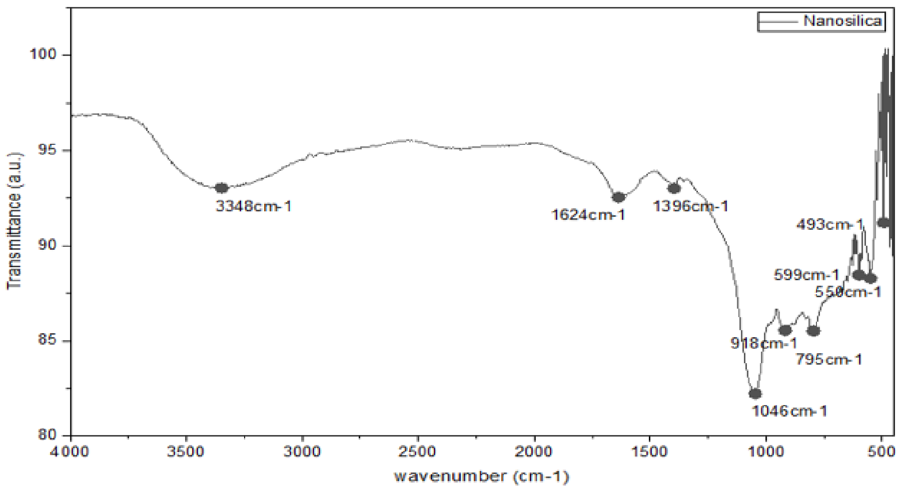

FIGURE 1. Graph of FTIR result

4.1. **Impact Test.** Impact value shows the resistance of the aggregate to sudden loads. It is used to determine the aggregate toughness, strength and durability. According to Table 1 is less than all other proportions, which is 10.8%, and the highest of them is the 100% RA, which is 17.6%. It is seen that with the increasing amount of RA, the impact value is also increasing, but as these three values are less than 20%, they are exceptionally strong [13]. Nevertheless, as the difference in the impact value of 0% RA compared to 50% RA is less, it can be an option to replace NA.

Table 1. Average Impact Values for Different Proportions

Percentage (%)	**Average Impact Value (%)**
0% RA	10.8
50% RA	12.3
100% RA	17.6

4.2. **Los Angeles' Test.** It is seen that Los Angeles' abrasion value also follows the same pattern as the aggregate impact value (Table 2). Los Angeles' test is carried out to calculate the aggregate resistance to wear and tear and also to find out the durability. The highest value of Los Angeles value is for 100% RA, which is 28.2%, and the lowest is the 0% RA, which is 23.3%, with 50% RA being in the middle, which is 25.6%. This also shows that with the increment of RA content, the abrasion value also increases. However, as the value is less than 30%, the aggregate is suitable for construction, as if it were more than 30%, it would have been only favourable to use on pavement [14].

Table 2. Average Abrasion Values for Different Proportions

Aggregate Replacement (%)	**Los Angeles' Abrasion Value (%)**
0% RA	23.3
50% RA	25.6
100% RA	28.2

4.3. **Water Absorption Test.** This test is carried out in order to find the permeability of the aggregate and to determine the amount of water a material can absorb under certain conditions. Table 3 shows that the water absorption value keeps increasing with the increment of RA, which shows that the value of water absorption is directly proportional to the amount of RA taken. The highest of them is the 100% RA (4.5%), which signifies that with the remaining residues of the RA aggregate, its water absorption capacity has increased. The smallest is the 0% RA, which is 2.5%, and with a low difference is the 50% RA, which is 3.2%. Seeing the difference, we can say that 50% RA can be an option.

Table 3. Water Absorption Values for Different Proportions

Aggregate Replacement (%)	**0% RA**	**50% RA**	**100% RA**
Water Absorption Value (%)	2.5	3.2	4.5

4.4. **Slump Test.** This test was carried out in order to find the workability of the concrete. Table 4 shows that as the proportion of RA increases, the slump generally decreases, showing that higher amounts of recycled material led to a less workable concrete mix. Nevertheless, the values of our proportion are workable as per IS 456:2000.

Table 4. Slump Values for Different Proportions

Proportion	**Slump Value (mm)**
100% NA	85
50% RA	80
100% RA	75

4.5. **Compressive Strength Test.** This test is carried out in order to ensure the capacity of that material to withstand axial load. The following proportions, as per Table 5, were taken in order to calculate the compressive strength of cubes. By seeing its result in 14 and 28 days, the proportion with 0%RA + 0%NS has given a strength of 19.14 N/mm^2 and 22.20 N/mm^2 in 14 and 28 days, respectively. While the strength slightly decreases with increment of RA but involving higher NS content which is 1.2% strength increases which was even higher than normal aggregate i.e. 20.8 N/mm^2 and 23.5 N/mm^2 in 14 and 28 days, however reaching the RA at 100% and even involving higher NS, the strength was significantly lower than the control mix but on reaching NS 1.2% the strength shows that it is quite workable i.e. 15.86 N/mm^2 and 20.02 N/mm^2 for 14 and 28 days respectively. The results indicate that NS significantly and effectively enhances the strength of Recycled aggregate concrete [4], which also suggests to us that the optimum combination is 50%RA + 1.2%NS.

Table 5. Compressive Strength Values for Different Proportions

Proportion	**Compressive Strength (14 days) (N/mm^2)**	**Compressive Strength (28 days) (N/**
0% RA + 0% NS	19.14	22.20
50% RA + 0.4% NS	18.32	20.20
50% RA + 0.8% NS	18.51	21.48
50% RA + 1.2% NS	20.80	23.50
100% RA + 0.4% NS	14.24	17.78
100% RA + 0.8% NS	15.40	18.36
100% RA + 1.2% NS	15.86	20.02

4.6. **Mean, Standard Deviation and ANOVA Tests.** Table 6 represents the mean value and standard deviation of the compressive strength of different proportions at 28 days. This table shows that mix 50% RA and 1.2% NS shows the highest mean strength whereas mix 100% RA and 0.4% NS shows the lowest. Similarly in terms of consistency 50% RA and 0.8% NS shows lowest SD indicating highly uniform whereas 100% RA and 0.4% NS shows the highest SD reflecting inconsistent result. Overall mix 50% RA and 1.2% performed best in strength whereas 50% RA and 0.8% NS was most consistent and mix 100% RA and 0.4% shows poor result in both mean strength and standard deviation.

Table 6. Mean and Standard Deviation Values for Different Proportions

Mix ID	**Mean (N/mm^2)**	**Std. Deviation (N/mm^2)**
100% NA	22.20	0.79
50% RA and 0.4% NS	20.20	0.83
50% RA and 0.8% NS	21.48	0.09
50% RA and 1.2% NS	23.50	0.21
100% RA and 0.4% NS	17.78	1.22
100% RA and 0.8% NS	18.36	0.32
100% RA and 1.2% NS	20.02	0.30

One way ANOVA tests was also performed in order to find the significance of compressive strength of different proportions that have been used. The test shows that p-value $= 4.516 \times 10^{-7} < 0.05$, indicating that the proportions significantly affect the compressive strength development.

5. CONCLUSIONS

With this study, it came to light that nanosilica can be extracted in a large amount with a water bath (18.56%) and in good quality with a hydrothermal process (20.8%), even though higher percentage and good quality was obtained from hydrothermal, higher amount can be extracted from water bath in one time which suggests that water bath can be a viable option to extract nanosilica for concrete preparation. It also shows that the behaviour of recycled aggregate and natural aggregate is quite similar to each other. Regarding the aggregate properties, the impact value of recycled aggregate (17.6%) is higher than natural aggregate (10.8%), but as both of them are lower than 20%, it is legit that the aggregate is tough. Aggregate abrasion value is also higher for recycled aggregate (28.2%) than for natural aggregate (23.3%). Being less than 30%, aggregate can be used for construction. Slump test results also show that the workability decreases with the increment of RA, but all the proportions are workable.

Finally, the compressive strength of 14 and 28 days proves that the involvement of nanosilica with a large amount of RA can be used as NA in concrete during construction. As it is seen that the compressive strength of 50%RA + 1.2%NS shows higher strength (23.5 N/mm^2) than normal concrete with 0%RA + 0%NS (22.20 N/mm^2). Also, the proportion with 100%RA + 1.2%NS also shows the desired compressive strength (20 N/mm^2) which also proves that the strength of aggregate enhances with the involvement of NS in concrete.

To sum up, 50%RA + 1.2%NS and 100%RA + 1.2%NS compressive strength shows that using nanosilica in concrete enhances the compressive strength of concrete, and a large amount of recycled aggregate can be used for construction, which ultimately reduces the pollution caused by rice husk and debris in society and promotes sustainability, reuse, reduction, and recycling in concrete and solid waste management.

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